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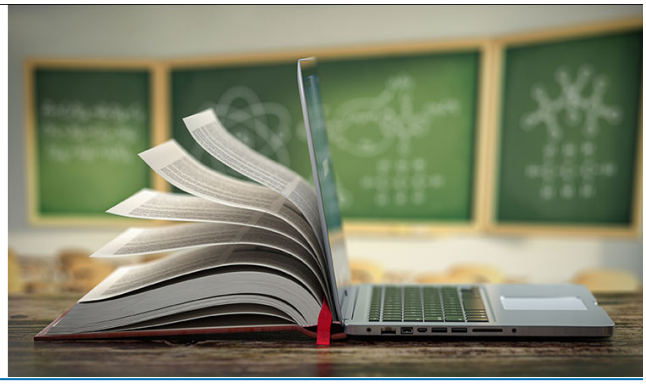

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Features of Shear Banding in Grains with Orientation {111}<110> in the Fe–3%Si Alloy

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Abstract. EBSD method were used to study the texture of BCC crystals {111}<110> Fe-3%Si. It is shown that in the state after cold rolling shear bands with habit plane at a slope of ~ 20–40° to the RD were formed as a result of 70% deformation. Theoretical analysis was performed and experimental data were analyzed which showed that the matrix reorientation into orientation {110}<001> occurs when grain stripping with orientation {111}<110>. Such effects are observed either due to rotation around the <100> axis or due to rotation around the <110> axis. By means of dislocation sliding, most of the SBs blocks are reoriented to orientations close to {111}<112>.

1. Introduction

Transformations, which determine the structure and texture of grain electrotechnical steel or Fe – 3% Si alloy (GOES) are caused by formation of sharp texture {110} <001> at one of the final stages of steel processing [1, 2], are not fully understood. One of the most important tasks in the process of texture formation in GOES is to create orientation {110} <001>. This can be achieved due to operations preceding secondary recrystallization. After significant cold deformation, the areas of orientation {110}<001> are formed in shear bands (SBs). Shift bands appear in crystallites {111}<112>, such areas then develop at primary recrystallization [3–7].

From the research point of view, the most mysterious element of the deformation mesostructure is SB. To date, a large amount of experimental data [8–17] on their morphology, the correlation between the matrix and crystallite orientation in the stripes, and their location in the matrix have been accumulated. Theoretical views of their formation are presented in detail in [18–23]. However, not all aspects of this issue are considered in them.

The main prerequisite for the formation of shear bands in crystals, i.e., loss of stability of homogeneous deformation, is the “hardness” of its orientation, characterized by a large Taylor coefficient [14]. The Dilmore theory assumes that strong localization of deformation in SB promotes macroscopic deformation of a crystal even without changing its orientation as a whole [18]. When rolling metal, regardless of the type of its crystal lattice, the SB should be located at angles close to ± 35 ° to the rolling plane. Formation of SB has another important aspect that connects the reorientation of the crystal lattice inside them with the geometric softening inside the plasticity model of Taylor [24]. SBs are treated as areas where the shift deformation is localized. However, little is known about their

internal structure and formation during cold rolling. Thus, it is important to study the basic laws of shear band formation to understand texture formation in GOES.

However, little is known about the internal structure of SPs when they are formed during cold rolling. Hence, it is necessary to study the basic laws of shear band formation. This approach can be useful for understanding texture formation in GOES.

Observation of texture evolution during secondary recrystallization shows that orientation {111}<112> is the main one, which is "absorbed" in the first place. This process is also related to SBs crystallography. Establishing this connection is also an important part of the problem to be solved. Orientation {111}<112> is dominant in the surface layers - the result of primary recrystallization GOES. It is likely that in the dominant after deformation orientations {111}<110>, {112}<110> SBs are the main “candidate” for the sources of grain formation with the orientation {111}<112>.

Presentation of results of research of Fe-3% Si alloy in the state of cold deformation, in which shear bands were formed in grains with orientation {111}<110> is the purpose of this paper.

2. Materials and methods

Samples were taken from a 0.65 mm thick Fe – 3% Si alloy in cold rolled condition. The total deformation was approximately 70%. The study of microstructure and texture was carried out with a scanning step of 0.1 and 0.025 μm using the JEOL JSM6490LV raster electron microscope at an accelerating voltage of 20 kV. The estimated error limit of the crystal lattice orientation was on average ± 0.6°, but did not exceed ± 1°. Misorientations from 2 to 15° were marked as small angular boundaries between local volumes. High angles were detected when the misorientation was ≥ 15°.

A coordinate system was adopted with the following axes: cold rolling direction (RD), normal to its plane (ND), and the direction perpendicular to both (TD).

Using the matrix of rotation R, which was obtained from the ratio $F_1=RF_2$, the misorientations between the crystal lattices of different orientations were determined. Where the matrix F, calculated from experimentally determined EBSD Euler angles, describes the orientation of the ferrite lattice. In the analysis to determine the closeness to the special misorientations of the CSL, the obtained matrices of rotation R were compared with the matrices corresponding to certain special misorientations from [25], by the method used in [26, 27]:

$$H_{ij} = C_j R^{-1} C_i T, \tag{1}$$

where matrix T_1 is used as T, describing the variant of special misorientation of CSL from [25], $C(C_J)$ – matrices of type $\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$ describing in general 24 symmetrical turns in a cubic lattice:

$$i(j)= 1, 2, \ldots, 24. \tag{2}$$

For each matrix of misorientation H, taking into account the full range of its symmetric variations, we calculated the values of angles Θ and pivot axes [uvw], using known mathematical formulas:

$$\Theta = \arccos\{[h_{11} + h_{22} + h_{33} - 1) / 2\}, \tag{3}$$

$$u : v : w = [h_{12} - h_{21}] : [h_{23} - h_{32}] : [h_{31} - h_{13}], \tag{4}$$

where h_{ij} are elements of H matrix. In the obtained sets of versions of deviation parameter values (angle and pivot axis) related to one H matrix, only one variant with the lowest angle value Θ was chosen. Matrix T corresponding to the given version was accepted as the closest special misorientation of CSL, and corner Θ was accepted as a deviation of experimentally defined orientation from orientation of CSL.

3. Results and discussion

The different propensity of different grain orientations to the formation of shear bands was established. Using orientation analysis of the microstructure with a large pitch (figure 1, a, b, c, grain I) it is shown that the banding does not occur in grains with an orientation close to {001}<110>.

Grains with orientation close to {111}<112> (figure 1, a, d, grain II) and {111}<110>, {112}<110> (figure 1 a, b, c, grain III and IV) contain stripes. Only in some areas was it possible to determine the orientation within SBs. For example, in grain II, the orientation inside SB corresponds to {110}<001> (figure 1, d). This corresponds to the misorientation ∑9 (or ∑27) according to [21–23].

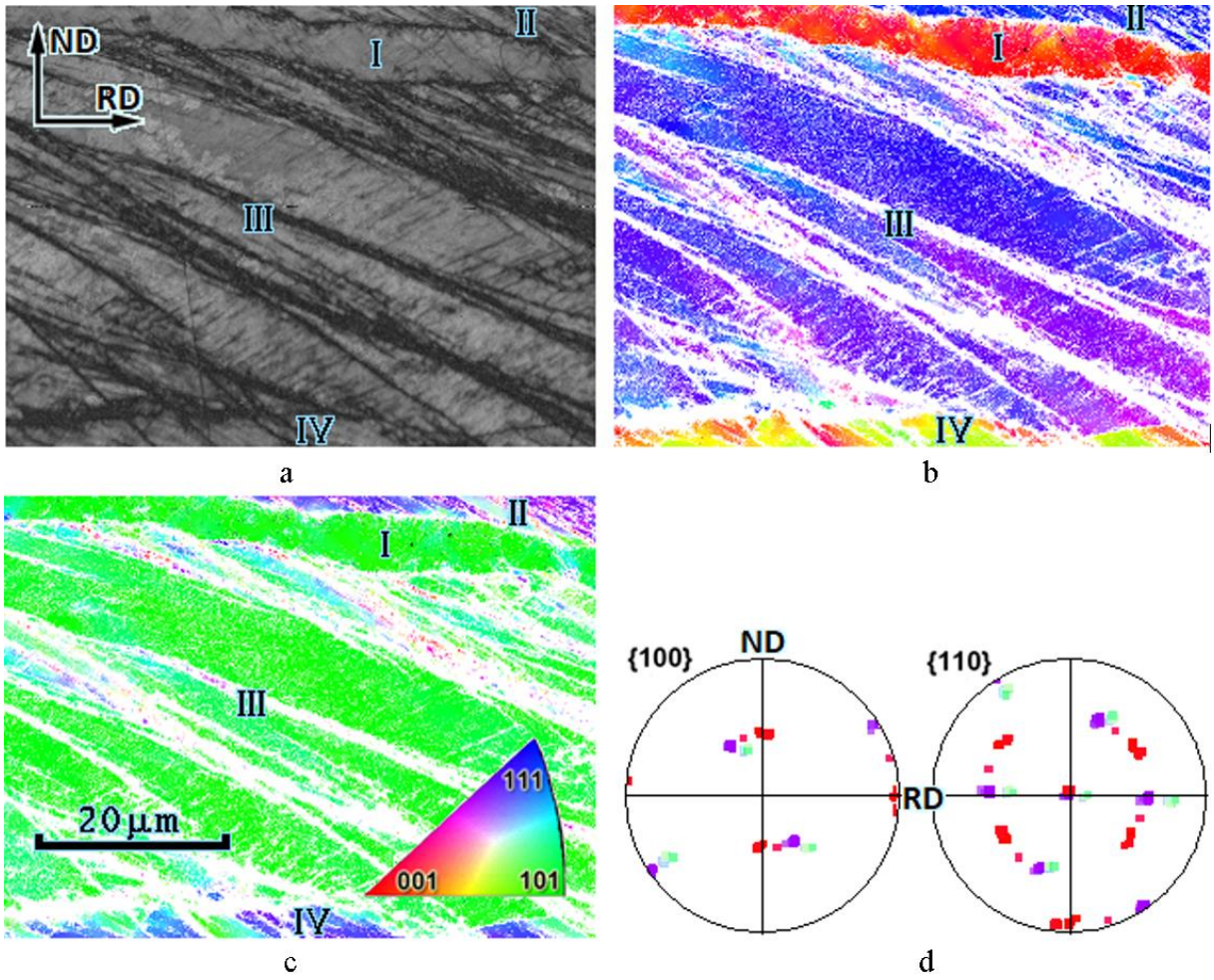

Figure 1. Microstructure of Fe-3%Si alloy polycrystal (4 grains: I, II, III, IV). Cold rolled state; deformation ε ~ 70%; EBSD: a – orientation map band contrast; b - orientation map from ND; c – orientation map from RD; d – DPF {100} and {110} of grain II.

The establishment of morphological and crystallographic features of SBs in grain with orientation close to {111}<110> (figure 2) was possible due to the increasing density of scanning points (step 0.025 µm). The fragment on figure 2 (a, b, c, d) contains three SBs characterized by close orientations in the central area, thus essentially differing in thickness (from 0.5 to 1.5 µm) and angles of a slope to a rolling plane ~ 20°, 35 and ~ 38°. Presumably, SBs were formed at different points in time, i.e. at different values of deformation. The strips have a block structure. The blocks are stretched along the plane of habitus. The length of the blocks reaches 2 µm. The number of blocks within the cross-section of wide SB varies from one to five. The misorientation between individual blocks can reach several tens of degrees. Central blocks of SBs have orientation close to {110}<001> with a significant magnitude of scattering (up to ~15° around the axis <uv0>). On both sides of wide SBs the orientations of peripheral

blocks are close. The orientations of these blocks are related by rotation at angles of 15-25° around the <110> axis close to the TD direction concerning the matrix orientation.

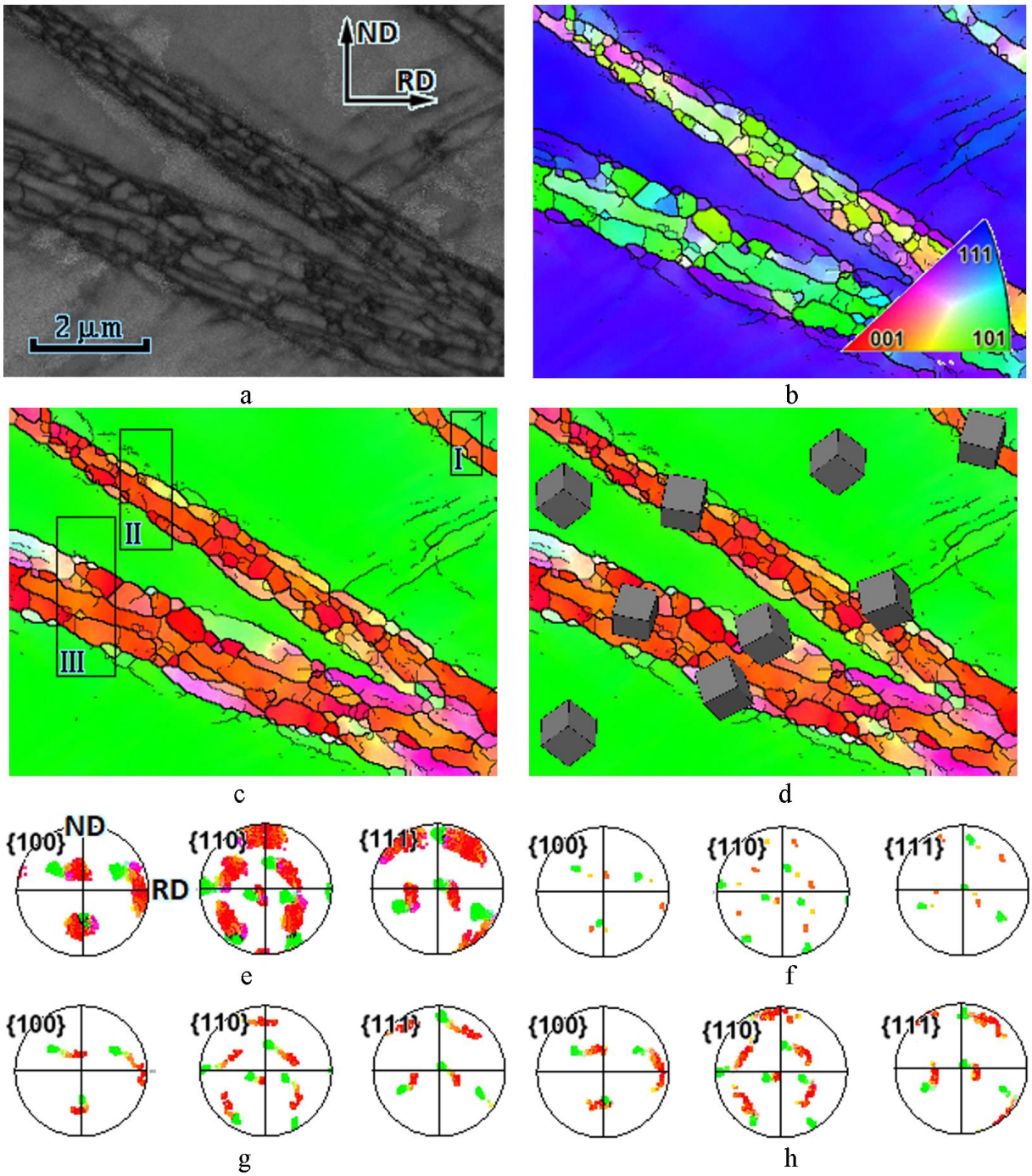

Figure 2. Microstructure and texture of Fe-3% Si single crystal {111}<110>. Cold rolled state; ε ~ 70%; EBSD: a – orientation map band contrast; b – orientation map from ND; c – orientation map from RD; d – orientation map from RD, indicating orientations of individual structural elements in the form of elementary crystalline cells; e-h – DPF {100}, {110}, {110} corresponding to the micro areas marked with rectangles in "c"; e – areas shown in "c"; f – I; g – II; h – III.

The vector analysis allows us to describe the misorientation between the central units of all SBs and the matrix orientation {111}<110> as CSL ∑15±(4-10°) (rotation angle 48.19° around the axis <210>),

which does not coincide both with the misorientation of ∑9 (or ∑27) in deformed grains {111}<112> and with the misorientation of ∑5 (or ∑29a) in deformed grains {110}<110> [17], but in some sense is intermediate between them. It should also be noted that the correctness of the analysis is significantly affected by the orientation scattering, which continues due to the deformation of both the SBs and the matrix orientation and is reflected in the DPF (figure 2, e, f, g, h).

4. Summary

Thus, it can be assumed that when the grain is banding with the orientation {111}<110>, the matrix undergoes a sharp reorientation into the orientation {110}<001> either due to the rotation around the <100> axis (less likely) or due to the rotation around the <110> axis (more likely). During further deformation, most of the SBs blocks are reoriented by dislocation sliding into orientations close to {111}<112>, which play a significant role in subsequent recrystallization processes.

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